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NUMERICAL STUDY OF FLOW FIELD CROSS-SECTION SHAPE AND LENGTH EFFECTS ON SOLID OXIDE FUEL CELL PERFORMANCE

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Abstract - Acomprehensive 3Dnumericalmodelwasdevelopedtostudytheanodesupportedsolidoxidefuelcell (SOFC) performance with different flow field cross – sections, Such as circular, rectangular, trapezoidal, and triangular. The model includes the momentum of charging (electron and iron), weight and energy conservation. The modeliss imulated numerically using ANSAYS FLUENT 16.0software.Theresultsare validated by usingopenliteratureexperimentaldata as they showed that the circular design provides higher performance compared to other designs.

Keywords - SOFC, Numerical, Flow Field, Performance.

I. INTRODUCTION

The Solid oxide fuel cells (SOFC), an electrochemical device, are able to transform hydrogen and more readily available fuels that contain carbon into electricity with both high effectiveness and also with low emissions[1] moreover, it is considered to be one of the most promising new energy technologies because it is not only has a high energy efficiency but also, it has the property to not pollute the environment[2].

Many studies were performed on the SOFC for its electrochemical performance; a numerical study was performed and it was stated that structural correlations in the SOFC can lead to the reduction in the thermal stress; so it will result in increasing its performance.[3]; A three-dimensional mathematical model was performed to study the performance of fuel cells with/without obstacles in the gas flow channels; and it was found that the maximum temperature of the fuel cell with obstacles is about 5 K lower than that of the fuel cell without obstacles and the application of obstacles in gas flow channels will increase the hydrogen utilization which is expected for the fuel cell [4].

A study was performed to test the influence of the flow field design on planar solid oxide fuel cell through using the conventional parallel flow field design and a new developed design; it was found that the parallel design achieved non-uniform distribution of velocity, species concentration and current density compared to the new design that attained more uniform distribution[5].

The presented study is conducted to investigate the performance of the solid oxide fuel cell in various flow field sections, for example, circular and rectangular, triangular and trapezoidal. The effect on cell performance from the flow field length is also investigated.

II. MATERIALS AND METHODS

2.1. Theoretical study

It was developed to investigate the performance of the planar solid oxide fuel cell with helical, single-entry serpentine parallel, modified parallel, double-entry serpentine and triple-entry serpentine flow channel, Hydrogen fuel is charged in the anode inlet side, while Oxygen is used for the cathode inlet. The governing equations developed for the model comprise electrochemistry, charge and mass transport, heat transfer, and fluid flows for SOFC[6]
The anode supported planar-type SOFC used in the validation of the current numerical study is shown in Fig. 1 and all dimensions of the investigated cell and its material properties are extracted from Refs[7-9] and it was summarized in Tables 1 and 2, respectively.

Parameter	Dimension, mm
Cell width	2
Cell length	19
Anode thickness	0.7
Cathode thickness	0.05
Electrolyte thickness	0.01
Channel height	1
Channel width	1
Current collector height	1.5

Table 1: Cell component dimensions:

Parameter	Anode	Cathode	electrolyte
Material	Ni-YSZ	LSM	YSZ
Density (kg/m^3)	4200	6350	6010
Specific heat (j /kg-K)	377	377	2000
Thermal conductivity (w/m-K)	11	2.37	2
Passion' ratio	0.2	0.25	0.3
Young's Modulus (MPa)	82	205	40
Thermal expansion coefficient (10^{-6} $1/C^o$)	13.2	11.4	10.4

Table 2: Material properties:

2.2. Numerical Methodology:

Grid independency tests are done to investigate grid convergence. In the current thermo-fluid analysis of the flow in cell channels, a solution with grid independency is reached by testing four different mesh densities varying from the coarsest grid, configuration "a", with 165.3 thousand cells, to the finest grid, configuration "d", with 376.2 thousand cells. A grid adaptive technique is utilized near walls through flow channels to better capture the boundary layer effect and mesh configuration "c", has 296.4 thousand cells. The reference parameter adopted through the computational simulation was performed by [(8-9)]; summarized in Table 3.

parameter	value	unit
Exchange current density(Anode)	10000	A/m2
Exchange current density(Cathode)	20	A/m2
Anode concentration dependence	0.5	
Cathode concentration dependence	1	
Anode porosity	0.3	
Cathode e porosity	0.3	

Table 3.Reference parameter:

2.3. Numerical solution:

The mass, momentum, energy equations, and charge transport model, are solved by ANSAYS FLUENT 14.5. The considered boundary conditions illustrated in Table 4 from references paper [9-12].

2.4. Modelvalidation:

A comparison between the current numerical model using standard materials, non FGM, with previous results, is performed and compared with the numerical and experimental results [6]

III. RESULTS AND DISCUSSION

3.1. Effect of flow field cross section on SOFC Performance:

It is illustrated in fig 2; where the all studied cross sections have the same height (0.5 mm) and width (1 mm) at the contact with the porous electrodes (Anode and Cathode).

3.2. The polarization and power density curve:

They are showed in fig 3; where it can be observed that the circular design gives higher performance compared to all other cross sections and this is due to that the circular design makes the best use of the fuel (hydrogen) as can be seen in Fig.4 where the hydrogen mass fraction at outlet is showed at the plane of x=1. Also it can be observed that the difference in performance for all designs is appeared at low voltage.

The cell performance increase with the increase of the cell length; also it can be observed that the difference in performance for the both designs appeared at low voltage due to the fact that polarization occurs at low voltage concentration (a huge number of reactions can occur but there is a little reactants) fig 5. The hydrogen mass fraction at outlet for the studied length and it is observed that the hydrogen mass fraction decreased with increasing the cell length (Fig. 6).

3.3. Temperature distribution:

The distribution of the current density for all the studied cross sections for the case of 0.3 volt at xy plane at z=18 mm; the case of circular cross section gives higher current density values more than all the other designs and this is due to that the case of circular designs successes to make the best consumption from the fuel (fig. 7).

3.4. Current density distribution:

The distribution of the current density for all the studied cross sections for the case of 0.3 volt at xy plane at z=18 mm; the case of circular cross section gives higher current density values more than all the other designs and this is due to that the case of circular designs successes to make the best consumption from the fuel (fig. 8).

3.5. Velocity distribution:

The anode velocity increases from inlet to outlet due to the generation of water vapor for the electrochemical reactions reaching maximum velocity of 33.97 m/s at outlet. Moreover, the circular design gives higher velocity distribution comparing to the rectangular design due to that the circular design succeed to make a higher number of electrochemical reactions compared to the rectangular design. In addition to both trapezoidal and triangular designs gives higher velocity distribution, and this is because their cross section is less than the ones for both rectangular and circular design (fig. 9).

3.6. Effect of flow field length on SOFC Performance:

Figure 10 shows the studied flow field length where the all studied cells have circular cross section with the porous electrodes (Anode and Cathode).

IV. CONCLUSION

A comprehensive 3D theoretical model has been developed to investigate the performance of a planar anode-supported solid oxide fuel cell (SOFC) with different flow field's designs and length at an intermediate temperature. Four designs has been studied and their effect on SOFC performance. The effect of the flow field designs such as circular, rectangular, Trapezoidal and triangular on the cell performance are studied using Ansys SOFC Module. The results show that the circular design gives higher current density compared to all other designs due to that the circular design succeed to make best use of fuel. Also the cell performance increase with increasing the cell length, so it can included that using circular flow field and increasing the flow field length has an important role in increasing the cell performance.

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Items	Boundary condition	Temperature, K	Species(mass fraction)		
			H_2	O_2	H_2O
Anode side inlet	Mass flow inlet (kg/s) 1.141×10^{-7}	1023	97%	None	3%
cathode side inlet	Mass flow inlet (kg/s) 2.287×10^{-7}	1023	None	100%	None
Terminal anode collector	Wall	Adiabatic	None		
Terminal cathode collector	Wall	Adiabatic	None		
Cell surroundings	Wall	Adiabatic	None		
Anode side outlet	Pressure outlet				
cathode side outlet	Pressure outlet				

Table 4: Cell boundary and operating conditions:

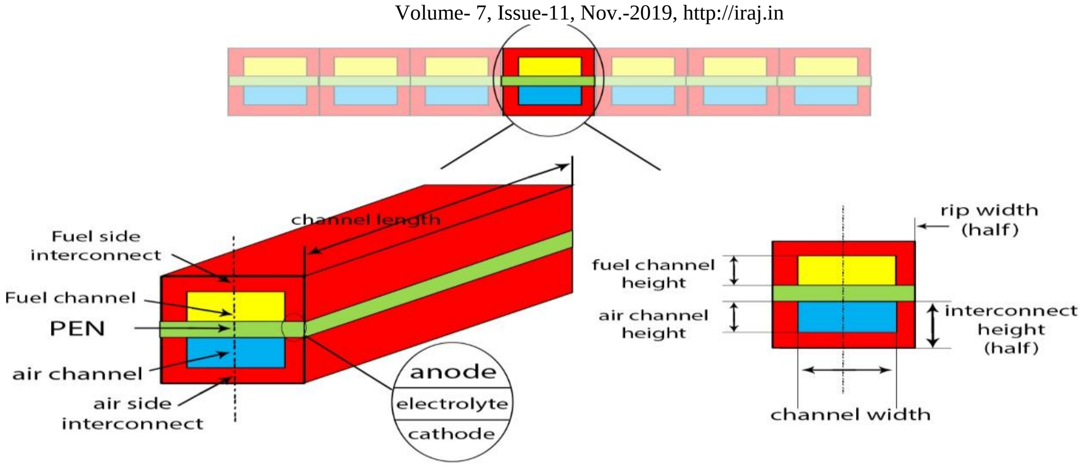

Fig1.Cell Geometry and coordinate system (ref)

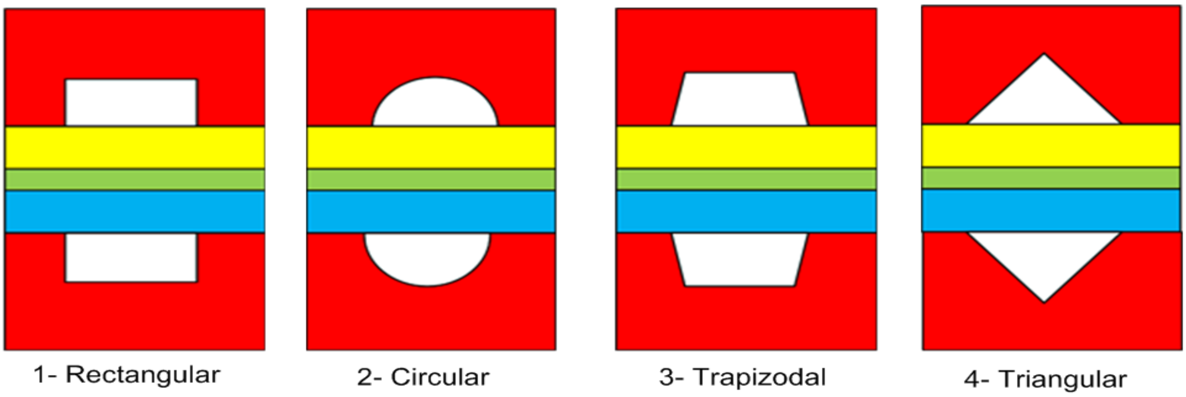

Fig.2 The Studied flow field cross sections.

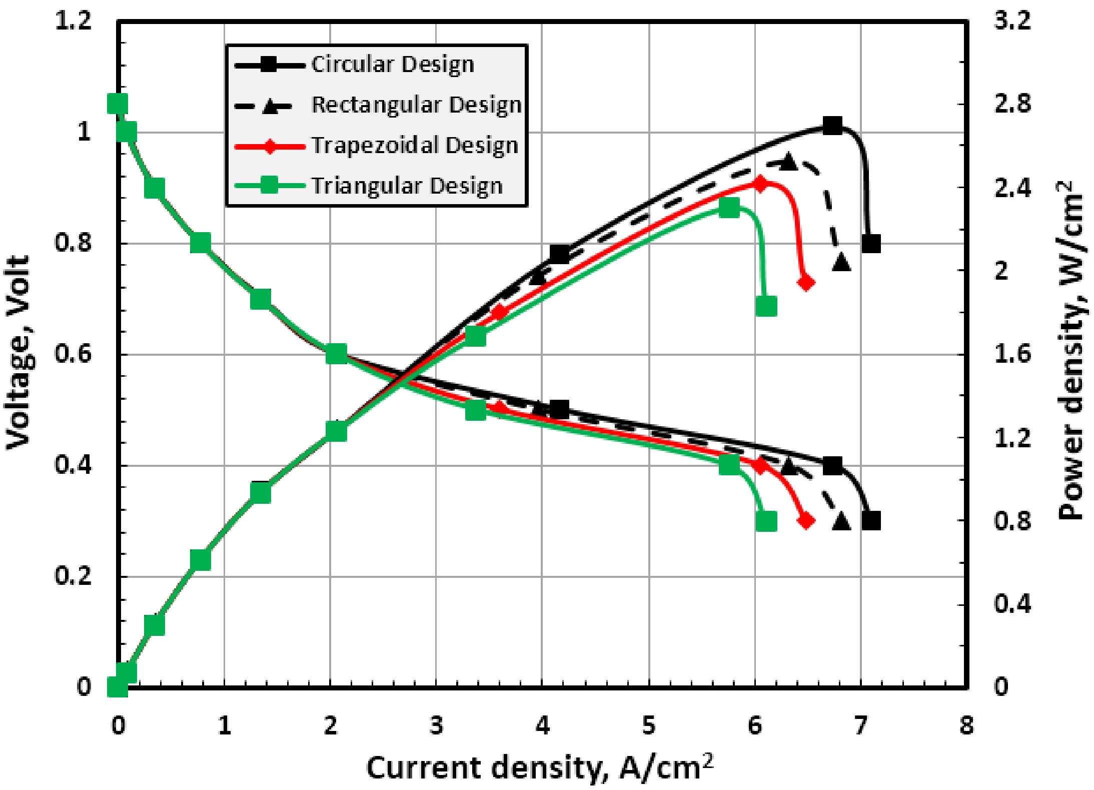

Fig.3. The polarization curve (I-V) and the power density curve for the studied cross sections.

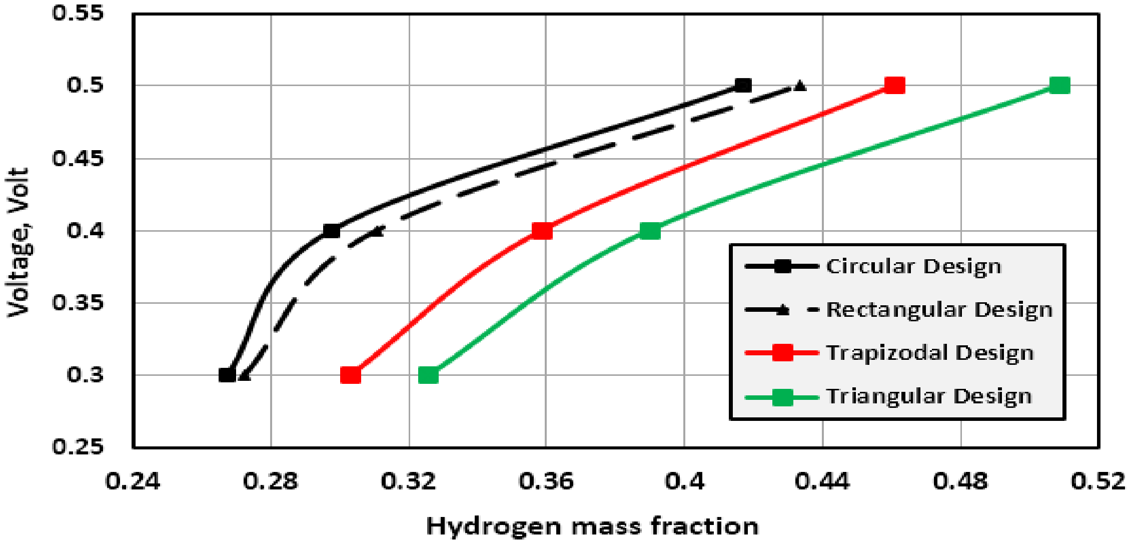

Fig.4The hydrogen mass fraction at outlet for all studied designs

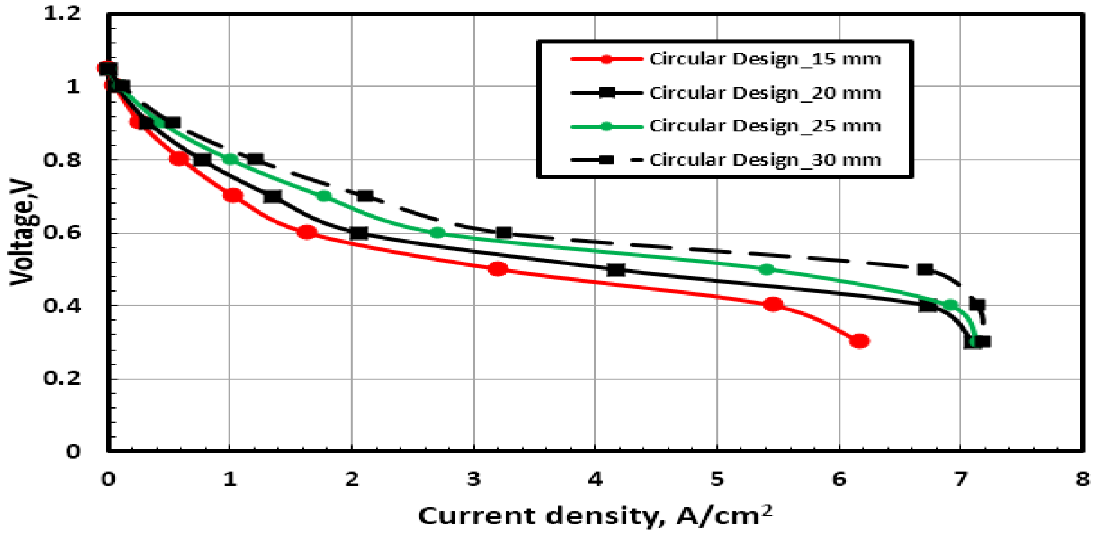

Fig. 5: the polarization curve (I-V) and the power density curve for the studied cross sections.

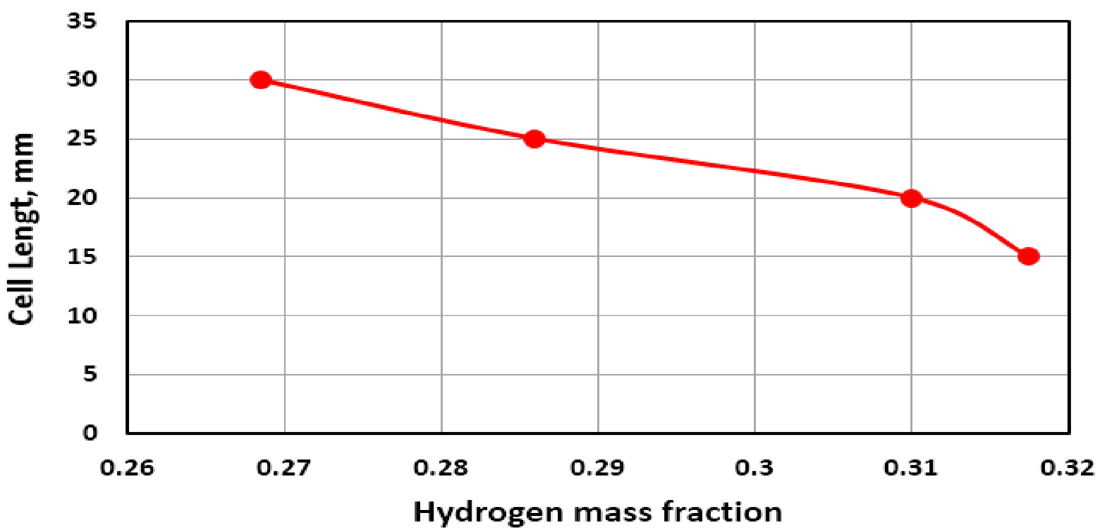

Fig.6: The hydrogen mass fraction at outlet for helical and one entry serpentine.

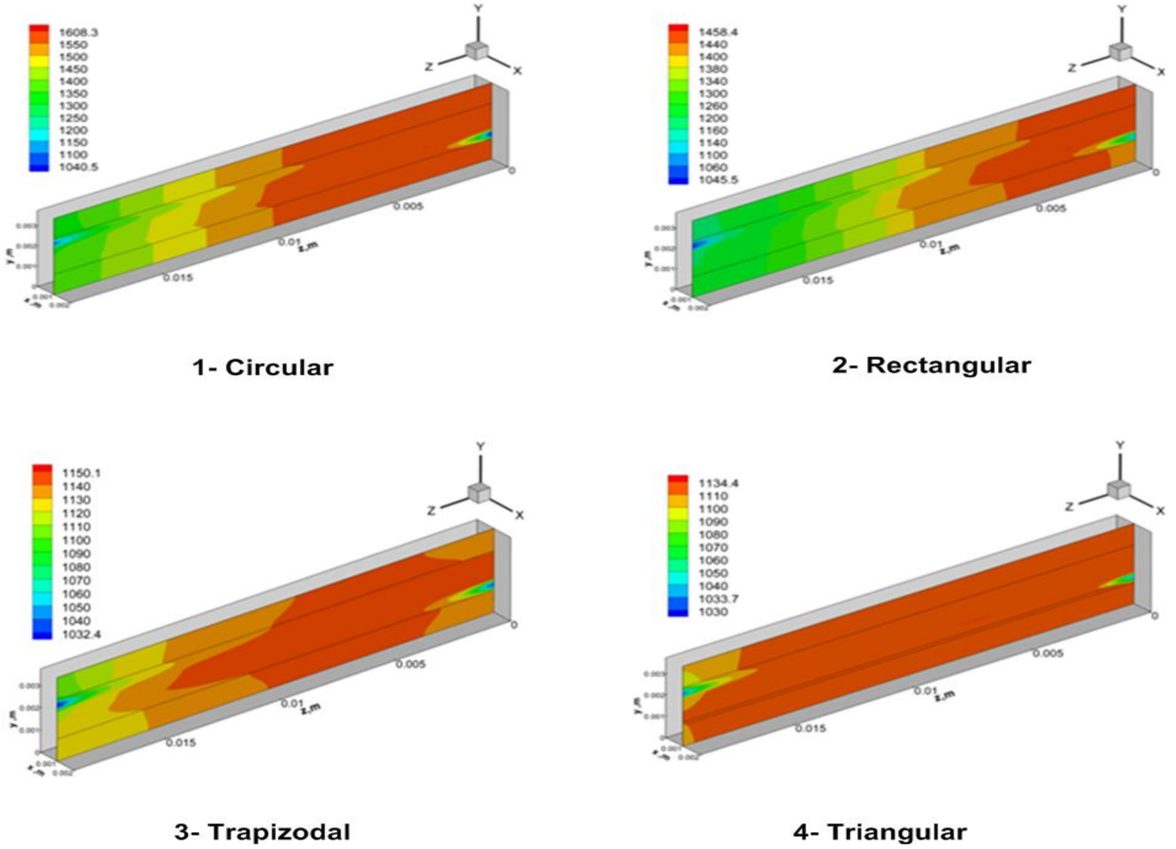

Fig.7: The temperature distribution at yz plane at x=1 mmfor all the studied designs.

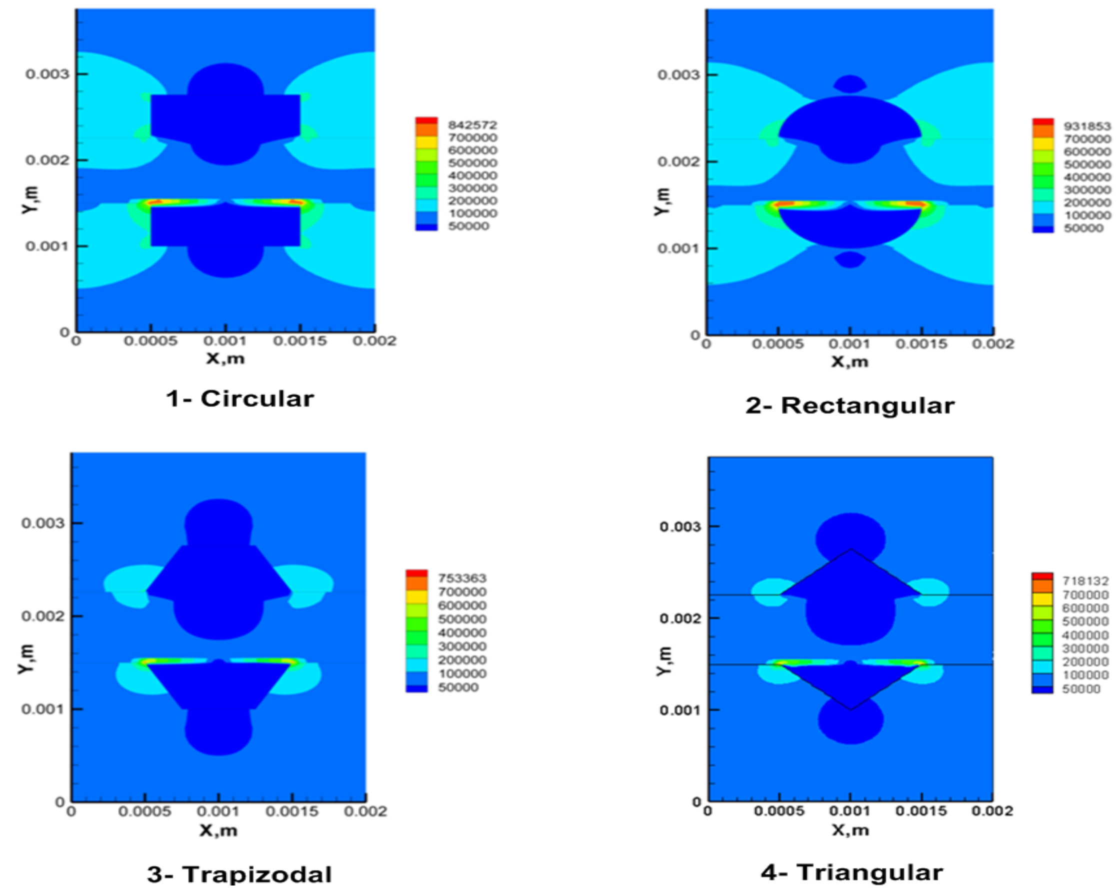

Fig.8: The current density distribution for all the studied designs at different planes.

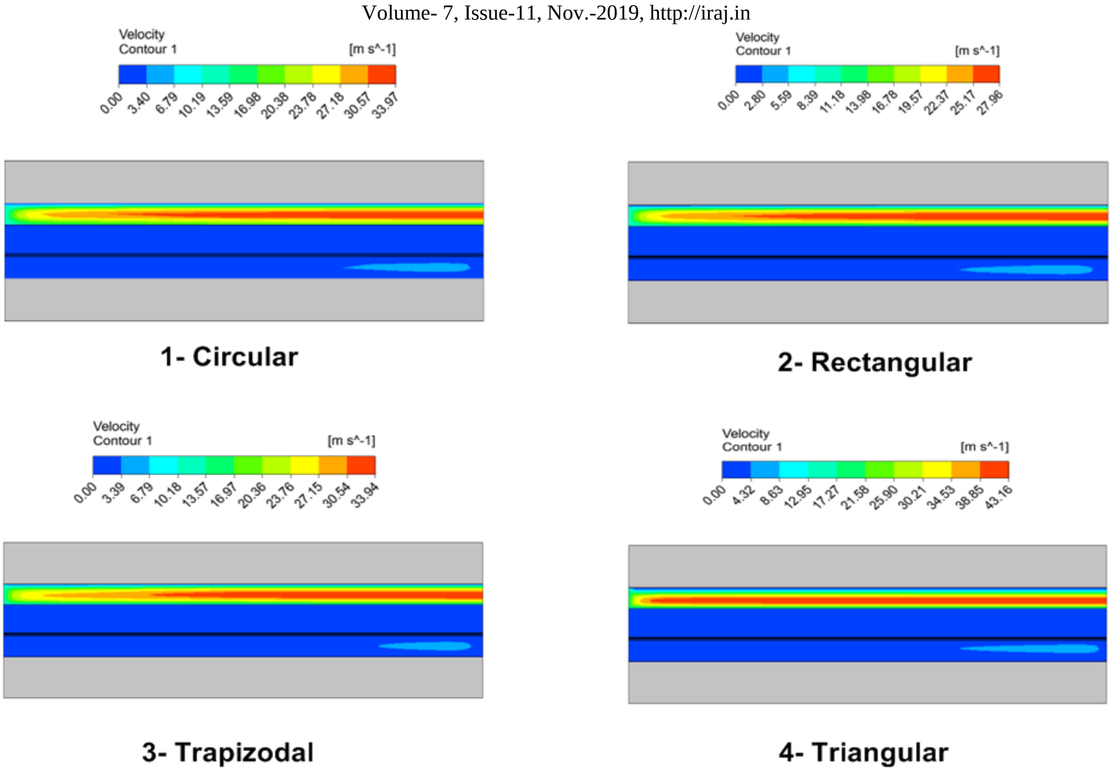

Fig.9: The anode and cathode velocity distribution for one entry serpentine.

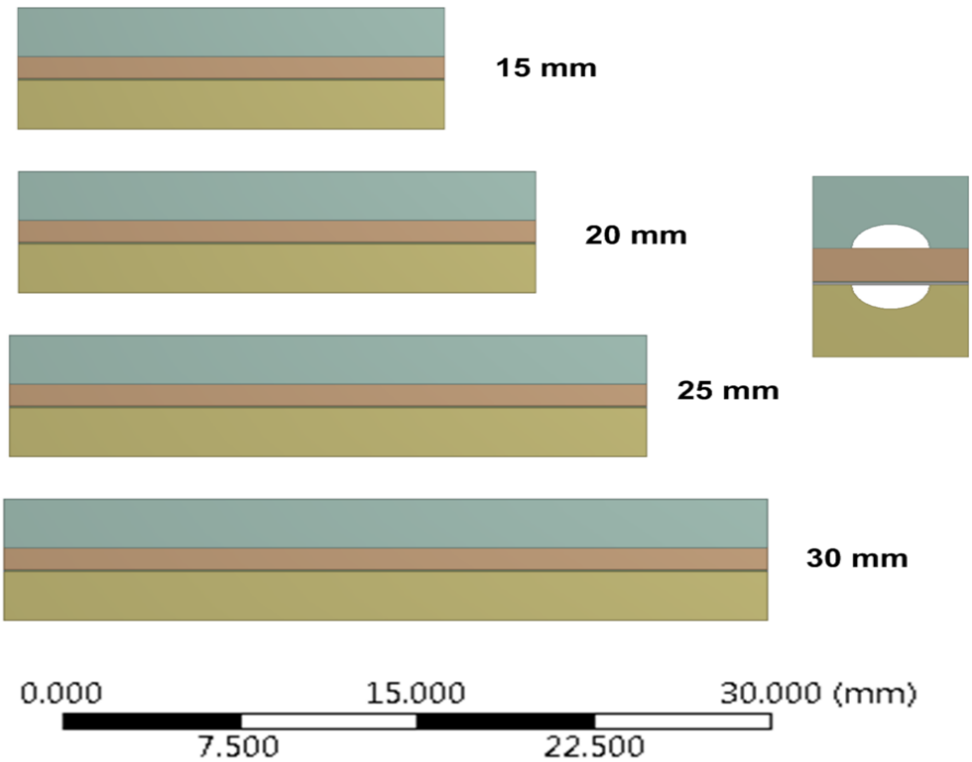

Fig.10: Studied flow field length.

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